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SUMMARY-ANALYSIS OF HEARINGS MAY 27–29, AND JUNE 3–7, 1957

ON

THE NATURE OF RADIOACTIVE FALLOUT AND ITS EFFECTS ON MAN

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SUMMARY-ANALYSIS OF HEARINGS HELD MAY 27-29 AND JUNE 3-7, 1957, ON THE NATURE OF RADIOACTIVE FALLOUT AND ITS EFFECTS ON MAN

INTRODUCTION

During late May and early June the Joint Committee on Atomic Energy held 8 days of public hearings on the nature of radioactive fallout and its effects on man. It was the intent of these hearings to emphasize the scientific subject matter related to the fallout problem, and to leave broader policy issues to subsequent consideration. The hearings, including material introduced for the record and a comprehensive bibliography, will probably be the most extensive library of information on fallout yet to appear in one document.[1]

The hearings covered in detail the whole cycle of fallout from its inception in the detonation of nuclear weapons, through its scattering about in the atmosphere and descent to earth, and finally its uptake by and effect on human beings, animals, and vegetation. Testimony covered a breadth of scientific knowledge from physics to pathology, and from geology to genetics, as it relates to fallout. Some 50 experts from the major scientific areas involved were invited to present testimony before the committee and submit statements for the record. All sessions were open to the public.

The hearings accomplished several things. One thing was clarification of many important scientific points. Another was putting into better perspective much of the available scientific data on fallout. Most helpful, in this respect, were experimental round-table discussions among some of the expert witnesses. The discussions helped to point up the areas of agreement and to outline more clearly the areas of continuing disagreement.

The hearings served to bring out distinctions that must be made between fact and value judgment, and served to emphasize how difficult it is to give precise scientific definition to such words as "clean," "safe," and "hazardous," so that these words acquire exact meanings.

The scope of the subject matter covered in the hearings is so broad and often so technical and detailed that a comprehensive analysis and evaluation is likely to involve a broad segment of the scientific and lay community in this country, and others, for many months to come. The purpose of this summary analysis is more immediate: To put down in simple terms a statement of what the hearings were about and what the main issues were. It is to be recognized that

[1] The oral testimony will constitute a major portion of the printed hearings which will also include statements inserted for the record. Selected reprints of previously published technical reports and scientific journal papers are also included. The extensive bibliography, prepared by Mrs. Ruth A. Little, Legislative Reference Service, Library of Congress, is an important part of the record of the hearings.

preparing even a summary necessarily implies making value judgments as to what is to be summarized. The summary does not cover all of the wealth of information available in the print of the hearings.

The proper discussion of fallout, its nature, its effects, and its policy implications requires an understanding of certain facts and concepts that are not ordinarily before the layman's eyes in easily understandable terms. The fallout hearings were aimed at bringing out these ideas and facts so as to promote a better understanding by the Congress and the public of this complex question. Much of the information contained in the print of the hearings is technical. One of the purposes of this summary analysis is to simplify and clarify this information.

The Joint Committee on Atomic Energy went to great lengths, first, to insure that all of the major areas of background subject matter in the sciences would be covered and, second, that important points of difference on what the facts are, or what they mean, would be covered so as to bring out clearly what differences exist.

On May 22, 1957, a statement of the scope and approach of the forthcoming fallout hearings, and an outline of the subject matter were made available to all prospective witnesses and to the public. This material included specific questions to guide witnesses as to points the committee felt should be covered or emphasized to assure a full and balanced presentation. Witnesses were picked out primarily from the point of view of their scientific competence and familiarity with particular aspects of the fallout problem. Obviously, not all scientists in the country meeting that criterion could come before the committee to testify. The committee tried to pick out a representative sample and to achieve a balanced presentation reflecting varied points of view.

The committee intended that the basic responsibility for adequate coverage and presentation of the subject matter would fall on the expert witnesses themselves. One of the most satisfying aspects of the hearings to the Congress and to the country should be the unstinting efforts of the expert witnesses to see that the subject matter was fully covered and made understandable.

Before coming to his own conclusions concerning fallout effects, a person should understand the basic scientific facts now available. Information in the field of fallout effects, as for many other scientific fields of inquiry, is far from complete. However, these hearings should provide enough information to help a person to begin to understand the problems and issues involved, to see what the present scope of information is, and to see the areas yet to be explored.

SUMMARY OF KEY POINTS

Some general observations may be made on the results of the hearings:

1. *Origin of fallout.*—It was pointed out that all nuclear explosions can be expected to produce some radioactive materials. However, certain kinds of explosions produce very much less radioactivity than others. Although there is no such thing as an absolutely "clean" weapon (that is, there is no such thing as a nuclear weapon detonation completely free of accompanying radioactivity), the amount of the

radioactivity produced can be substantially altered in relation to the size of the explosion.

2. *Distribution of fallout.*—There was substantial, but far from complete, agreement on what happens to radioactive debris produced in man's environment, how much is there now, how and where it is distributed, and how much is in man himself. There was considerable evidence presented to indicate that in no part of the atmosphere is fallout uniformly distributed and that, therefore, the effects of fallout on the world's population could not necessarily be expected to be uniform.

3. *Biological effects of radiation.*—There was general agreement that any amount of radiation, no matter how small the dose, increases the rate of genetic mutation (change) in a population. There was, on the other hand, a difference of opinion as to whether a very small dose of radiation would produce, similarly, an increased incidence of such somatic (nongenetic) conditions as leukemia or bone cancer, or a decrease in life expectancy, in a population.

4. *Tolerance limits.*—There was general agreement that there is a limit to the amount of radioactivity and, hence, to the amount of fission products that man can tolerate in his environment. The extent to which existing and future generations will be affected by manmade radiation was shown to be intimately tied to certain decisions, moral as well as scientific, that must be made as to how much radiation can be tolerated by the peoples of the world.

5. *Effects of past tests.*—It was clearly shown that man's exposure to fallout radiation including strontium 90 is and will be in general small, *for the testing already done*, compared with his exposure to other, "normal background" sources of radiation (a fraction of 1 to 10 percent), and even compared with variations in "normal background" sources. But it was not agreed on how this information should be interpreted.

6. *Effects of future tests.*—There were differences of opinion on how to forecast the consequences of further testing. The differences hardest to reconcile appear to be those concerning the biological effects of radiation. Pending a resolution of differences, it would appear from the information presented that the consequences of further testing over the next several generations at the level of testing of the past 5 years [2] could constitute a hazard to the world's population. It is very difficult, if not impossible, to forecast with any real precision the number of people that would be affected.

7. *Effects of nuclear war.*—The catastrophic nature of the radiation effects from a multiweapon (atomic and hydrogen bombs) attack on the United States were clearly portrayed. This, of course, could be applied to any nation.

These points will be discussed in more detail.

MAJOR UNRESOLVED QUESTIONS

A number of unresolved questions emerged from the hearings. Among the chief of these are—

1. How "clean" can nuclear weapons actually be made? The solution to this question lies in the future of weapons development;

[2] It has been estimated that about 50 megatons equivalent yield of fission products have been put into the atmosphere so far by all countries.

2. To what degree is the distribution of radioactive fallout uniform or irregular throughout the world? Vigorously conducted sampling programs will help to answer this question.

3. To what extent do the biological processes of plants, animals, and human beings—under normal conditions—exhibit a preference for or "discriminate" against strontium 90 and other potentially hazardous isotopes that are taken up into the human body? Sampling and metabolic studies underway will develop a better answer to this question.

4. Is there a "safe" minimum level of radiation or "threshold" below which there is no increase in the incidence of such somatic (non-genetic) conditions as leukemia or bone cancer, or no decrease in life expectancy, in a population, resulting from radiation? The answer to this question appears difficult to find experimentally.

5. What is the genetic "doubling dose" of radiation to man? That is, what dose of radiation will cause the spontaneous genetic mutation (change) rate to double?

6. Should a distinction be made between absolute numbers of persons affected by fallout and percentages relating these numbers to the total population of the world, i. e., can we accept deleterious effects on a relatively small percentage of the world's population when the number of individuals affected might run into the hundreds of thousands? This question cannot be answered by considering scientific data only. Overall national policy and great moral issues are also involved.

These questions will be discussed in greater detail.

Need for further research

There was strong agreement among the witnesses that even greater efforts and even larger budgetary outlays, both private and governmental, are required for our research program in the sciences related to fallout. There was testimony advocating sharp increases in budget, with emphasis in specialized fields. There was also testimony for more gradual long-term increases with emphasis on stability and continuity. But most witnesses appeared to feel that some increase is necessary if we are to accomplish our objectives of understanding the nature of radioactive fallout and its effects on man at an earlier date.

DETAILED DISCUSSION OF THE RESULTS

Natural "background" radiation

Information appears in the hearings about the kinds and amounts of radiation that exist naturally and to which man is and has been historically exposed. This radiation comes mostly from naturally existing radioactive materials that emit radiation (some of these materials are present in man himself) and from cosmic rays emitted from outer space. The following table shows a breakdown of the average natural background radiation dose rate to the skeleton as evaluated by Drs. Evans and Dudley:[3]

[3] Dr. Shields Warren pointed out in testimony that in India a large population has lived for many centuries in a monazite rock area where the background levels are 5 to 20 times average natural background. According to testimony, while the effects have not been obvious enough to cause the population to abandon the region, one cannot say what the effects have been until careful studies are made.

Average natural background radiation dose rate to the skeleton (Dudley, Evans)

Source of radiation	Skeletal dose rate	
	Millirem per year [1]	Percent of total [2]
Potassium-40 (internal)	8	6
Radium-226 (internal)	12	9
Mesothorium (internal)	12	9
Radium D (internal)	12	9
Cosmic rays (external) [3]	30	22
Local gamma rays (external) [4]	60	45
Total	134	100

[1] A millirem is 1/1000 of a rem. A rem is a unit of absorbed radiation dose that allows for the different biological responses to different types of radiation. See Dr. Taylor's testimony in the hearings for definitions and discussion of units.
[2] As computed by the JCAE staff.
[3] According to testimony by Dr. Evans and Dr. Dudley, cosmic ray dosage varies from 24 to 39 millirads per year (and hence millirems for a relative biological effectiveness of 1 as used by them) at 30° latitude, corresponding to sea level and 6,600 feet altitude, respectively.
[4] Local gamma radiation occurs in man's natural environment from 3 important series of radioactive isotopes: the uranium series, the thorium series, and potassium 40. The amount of radiation in the environment depends on the location, the kind of rock, the amount of shielding, etc.

Testimony appears in the hearings comparing radiation levels from fallout from *past* tests with natural background radiation levels. The point emphasized in the hearings was that man's lifetime exposure to fallout radiation from strontium 90 and his exposure to external fallout radiation *from the testing already done*, ignoring local fallout, is and will be small compared with natural background radiation doses, and even the variations in natural background. Individuals have, of course, received exposures from local fallout that exceed considerably the natural background levels. The interpretation of the point discussed here was not agreed upon, however.

The reason natural background radiation levels are important is that they are used as a yardstick for evaluating the biological effects of radiation. Thus, the National Academy of Sciences summary report on the biological effects of atomic radiation, in the report of the committee on genetic effects, illustrates the use of natural background levels as the basis for estimating genetic "doubling doses."

The consequences of further testing are discussed later.

Nonweapon manmade radiation to which man is exposed

Typical sources of radiation created by acts of man and causing potential hazards to man are X-ray machines, fluoroscopes, and radioactive waste products. Another source is radium. The hearings did not cover the subject of nonweapon manmade radiation in detail, although some background information appears. The committee recognizes the possible existence of hazard from these sources of radiation and plans to look into this question in the future.

The inseparability of radioactivity, radiation, and nuclear energy processes

When man explodes a nuclear weapon or operates a nuclear reactor, he deals with a nuclear process. The two principal nuclear processes associated with energy production are fission and fusion. Fission is a splitting of the atomic nucleus into fission products, neutrons, and energy. It is the radioactive nature of many of the individual species of fission products that is the source of much of the radiation associated

with nuclear weapons fallout and with nuclear reactors.[4] Fusion is a combining of atomic nuclei into new nuclei, neutrons, and energy.

The sources of fallout: Nuclear weapon explosions

All nuclear weapon and nuclear "device" explosions produce measurable amounts of radioactivity and radiation. That part of the explosion energy yield that results from fission processes is related to the quantity of radioactive fission products produced. That part of the explosion energy yield that results from fusion processes is related to the quantity of fusion products produced. Neutrons are always produced. These, when they escape, induce radioactivity in surrounding materials. In general, the radioactivity from fission products as a class is considerably more dangerous than the radioactivity induced in the environment by neutrons. The relative fission to fusion yields at which the two kinds of radioactivity become comparable in danger was not discussed for security reasons. The amount of fission products produced per kiloton of blast yield depends strongly on the weapon design. Although there is no such thing as a weapon detonation completely free from accompanying radioactivity, the amount of the radioactivity produced can be substantially altered at least in certain weapon designs.

Specific weapon characteristics, such as energy release, fission product production, neutron production, etc., were not discussed in detail for security reasons. In general, these characteristics can be made to vary over wide ranges depending upon the weapon design.

The following characteristics of nuclear weapon explosions determine the nature and amount of fallout resulting:

1. The size of the explosion (that is, total energy yield, usually expressed as a certain number of kilotons or megatons of TNT explosive energy equivalent);[5]
2. The percentage of the total energy yield resulting from the fission process;[6]
3. The type of detonation (high in the air, near the ground, under water, etc); and
4. The nature of the surface material where the explosion takes place (water, rock, sand, coral, etc.).

Air detonations of nuclear weapons favor wide dispersion of fallout because the sizes of the radioactive particles produced are relatively small; surface and under-the-surface detonations favor local fallout because the particle sizes tend to be relatively large. Low-yield weapon explosions produce fallout that generally does not penetrate the stratosphere; high-yield weapon explosions produce fallout a substantial part of which in general does penetrate the stratosphere.[7]

Local fallout: Its behavior and effects on man

There is no precise dividing line between local fallout and fallout that is more widely distributed, even worldwide. Generally speaking,

[4] Something like 200 or more different isotopes have been identified among the fission products. The reason is that some of the isotopes formed in fission decay into still different isotopes. Strontium 90 is formed this way.

[5] Thus, a 1 kiloton bomb has the same explosive energy release as 1,000 tons of TNT (a common explosive), a 1 megaton bomb has that of 1 million tons of TNT, etc. The Hiroshima bomb yield was estimated at 20,000 tons of TNT, i. e., 20 kilotons.

[6] Thus a single 10-megaton bomb (a so-called H bomb) at only 10 percent fission yield is equivalent to 50 20-kiloton all-fission bombs.

[7] The atmosphere around the world is divided for purposes of this discussion into 2 parts: (1) The troposphere, the part below 35,000 to 45,000 feet which contains all of what we generally know as "weather" and, (2) a region above 35,000 to 45,000 feet called the stratosphere. The altitude of the troposphere varies from the equator to the poles.

the division is made not only on the basis of nearness to the explosion but also on the basis of the time it takes the radioactive debris to fall out after the explosion. Local fallout consists of the larger particles of material originally thrown up into the air by the explosion. These larger particles tend to fall out within a few hundred miles of the explosion at most, and within a few days of the explosion. Among the effects of local fallout are high level radiation from beta and gamma rays [8] to which man is exposed externally and large quantities of certain isotopes (such as iodine 131, cesium 137, and strontium 90) that may be taken up into man's body through the food he eats, and otherwise, and may stay in the body for extended periods of time.

The more widely distributed fallout consists of the smaller particles put up into the air by the explosion.

Figure 1 shows pictorially the different types of fallout. These smaller particles, depending upon how high they rise, tend to remain in the atmosphere for periods of time ranging from weeks to years, and so become widely distributed. The radioactive materials in this widely distributed fallout do decay, however, so that the exposure of the body to high external radiation is generally not associated with this type of fallout. However, specific isotopes, particularly strontium 90, do remain and may be taken up into man's body through milk, vegetables, and other foods, and may remain in the body for long periods of time.

Local fallout tends to produce both "acute" and "chronic" radiation effects. Acute effects as used here are such things as radiation sickness, skin burns, other clinical symptoms of damage—and death—depending on the size of the dose. Chronic effects as used here are such things as cancer (leukemia, bone cancer, etc.), generally lowered resistance to stresses, premature aging, and premature death, again depending on the size of the dose.

The more widely distributed fallout, by nature resulting in lower levels of radiation, tends to produce only the chronic type of effect.

Local fallout: The effects of nuclear war

Local fallout can cover tens or hundreds of square miles from kiloton explosions and thousands of square miles from megaton explosions. About half of all the fission products produced from ground explosions come down in local fallout, although some estimates tend toward four-fifths.

For instance, multiweapon attacks (say 200 to 300 bombs of megaton size, 2,500–3,000 megatons total yield), can blanket half or more of the continental United States with lethal (death-producing) or near-lethal radiation levels from local fallout alone. This, of course, could be applied to any nation. In addition to the acute effects in survivors as described above, chronic effects and genetic effects involving existing and future generations can occur. These chronic and genetic effects are always a byproduct of any acute exposure to radiation.

[8] Types of radiation: *Alpha particles;* The nuclei of helium atoms, swift moving, high energy, little power of penetration, but biologically very destructive if they arise within living tissue, for example; *beta particles;* fast-moving electrons, of varying energy and varying penetrating power, but generally more penetrating than alpha particles; *gamma rays;* radiations of high energy, great penetrating power (the more penetrating gamma rays can travel through the whole body with little absorption); there are also neutrons and X-rays. Radium 226 emits alpha particles; strontium 90 emits beta particles; cesium 137 and its short-lived daughter element barium 137 emit beta particles and gamma radiation.

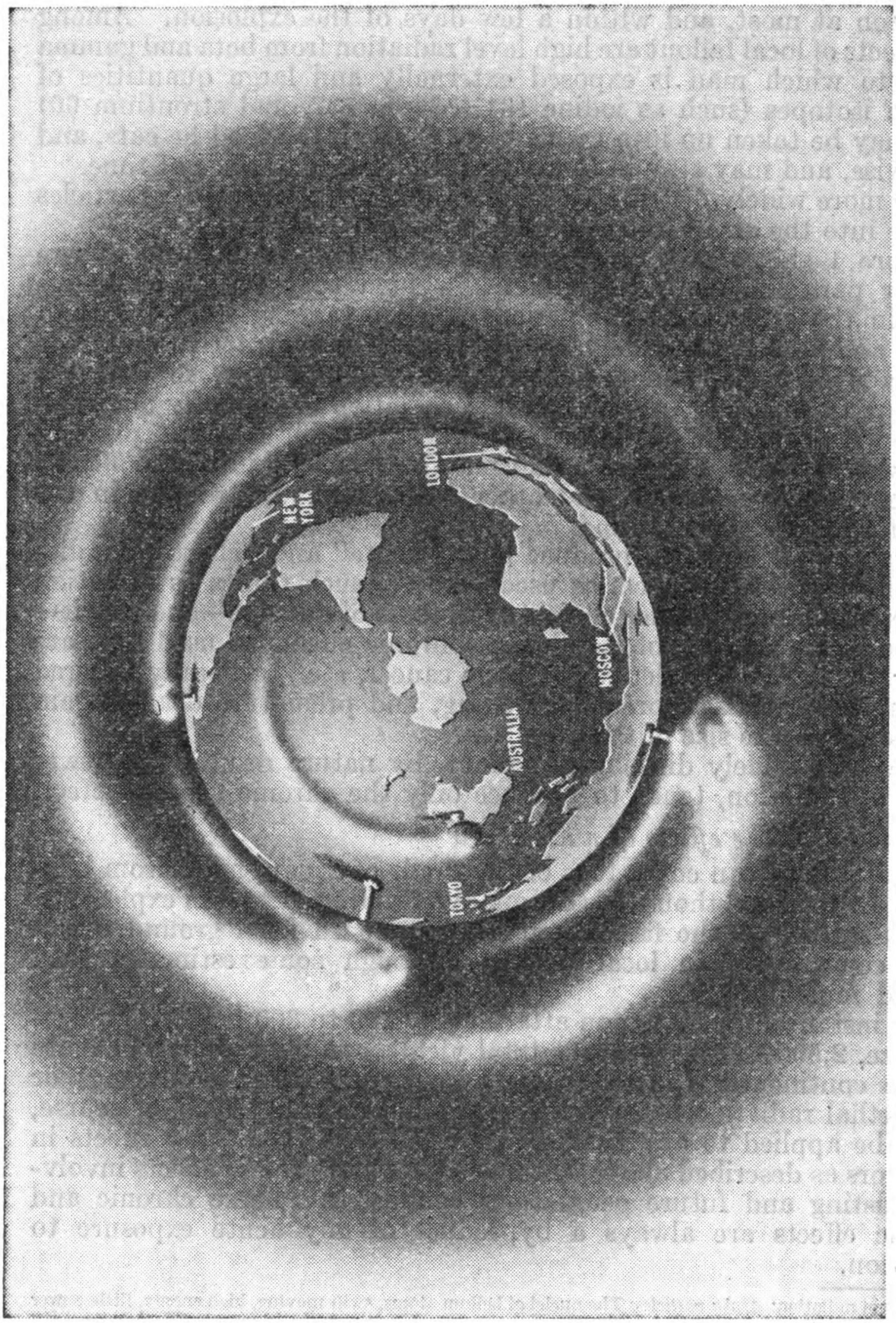

FIGURE 1.—A pictorial representation of types of fallout produced by weapons explosions. The light band close to the earth represents tropospheric fallout. The outer band represents stratospheric fallout. Local fallout occurs near the site of the explosions. [Figure reprinted from testimony of Drs. Langham and Anderson, Los Alamos Scientific Laboratory.]

Because of difficulties of forecasting in advance such information as the weather, the exact locations of detonations, and the exact characteristics of weapons, it is to be expected, as pointed out in the hearings, that there would be great difficulties in forecasting local fallout patterns associated with a nuclear war.

Although strontium 90 is most often thought of with nonlocal fallout, it was clearly brought out that strontium 90 levels with local fallout can amount to 100–300 times the number of strontium units [9] in animal bones as are now considered permissible in human bone, from 1 large megaton weapon alone.

For an attack of the sort mentioned here, countermeasures based on shelters, for early survival, plus reclamation measures, are necessary to cope with the situation. In any event, the effects of such an attack would be catastrophic, even if there were no fallout resulting.

Nonlocal fallout: The behavior of the more widely distributed fallout in the atmosphere

The hearings made it clear that an extensive research effort is presently underway directed toward examining critical parts of man's environment for the nonlocal (delayed and widely distributed) fallout, particularly for the long-lived isotope, strontium 90. Soil, human bones, milk, fish, vegetables, crops and animals, and the atmosphere itself, are being sampled all over the world. One of the prime purposes of this sampling is to try to determine the extent to which nonlocal fallout descends to the ground uniformly and the extent to which it falls out nonuniformly or unevenly.

Data presented at the hearings based on the sampling program show a strong tendency toward nonuniform distribution for the more widespread fallout. Samplings taken on the ground at different points along a line from the North Pole to the South Pole show this point clearly. Furthermore, testimony given in the hearings indicates that such a situation of nonuniformity can be predicted. This nonuniformity could result from the direct fallout from the troposphere (which is inherently nonuniform) and from injection of unevenly distributed stratospheric fallout into the troposphere through activity of the jet stream. The concept of nonuniform *stratospheric* fallout is in distinction to an earlier concept that held stratospheric fallout to be uniformly distributed. The earlier concept used a period of from 5 to 10 years as an average time during which the particles are stored in the stratosphere. The testimony brought out the fact that high-altitude sampling programs now underway should throw more light on these questions in a year or two.

Storage time in the troposphere is estimated in weeks or months, at most. Directly influencing the distribution of fallout on the ground is the local weather. Rain, for example, is identified as an important means by which radioactive particles are removed from the atmosphere to the earth's surface.

From 50 to 70 percent of the total nonlocal fallout is expected to deposit in the ocean, since the oceans cover about 71 percent of the earth's surface.

The question of whether uniformity exists is an important one. If it cannot be resolved, this will indicate that one really does not know

[9] A strontium unit is the same as, but in the minds of the committee much better named than, a "sunshine unit," that is, 1 micromicrocurie of strontium 90 per gram of calcium; 100 strontium units is the presently established maximum permissible concentration of strontium 90 in man, for a population.

with any assurance where the fallout now up in the air really is and where it will come down. Furthermore, forecasts of *future* amounts of radiation at ground level resulting from *more* testing (or even from *past* testing) depend upon an assumption as to the degree of uniformity. It appears that past forecasts are in need of review for possible revision to take into account information presented at the hearings.

Figure 2 illustrates the general levels of world-wide fallout deposition, as of the fall of 1956, as taken from testimony.

Nonlocal fallout: Behavior in man and in man's biological environment (the biosphere)

Fallout, once deposited on the ground or on plants, may be expected to enter into earth processes in a manner consistent with the chemical properties of the individual chemical elements involved. A large fraction of strontium 90, for example, is available for entry into the human food chain through uptake by plants. This fact is known because isotopes such as strontium 90 have been found in soils, plants, food, and milk in most parts of the inhabited world. The highest levels appear in the Northern United States and Southern Canada. The biological processes in which strontium 90 participates are not completely understood, although there was much agreement. Broadly, these processes are as follows: strontium 90 present in the upper layer of the soil is taken up directly by plants. In addition, strontium 90 may be deposited directly on the surfaces of plants. If these plants are eaten by animals, such as cattle, the strontium 90 will appear in the animal's milk. If man drinks the milk, or if he eats plants directly as food, strontium 90 will appear in man's own body. In particular, strontium behaves in a manner similar to calcium and is a "bone seeker," that is, virtually all of the strontium that stays in man's body has a tendency to seek the bone.

While strontium behaves in a manner similar to calcium, it does not behave exactly as calcium does. Many of the biological processes just described exhibit a preference (discrimination) for calcium rather than strontium. Much animal and some human experimentation has been carried out to establish the behavior of strontium in biological processes. Furthermore, stable (i. e., nonradioactive) isotopes of strontium behave *chemically* in a manner identical to strontium 90. Measurements of stable strontium have been made in soils and human bones. Scientists generally agreed that the correct value for the overall strontium 90 discrimination factor from soil to human bone is from 4 to 20, depending upon the diet, the soil characteristics, etc.[10]

A similar discussion would apply to the radioactive isotope, cesium 137. Cesium 137 and strontium 90 have comparable half lives [11] but the time cesium stays in the body is considerably shorter. Cesium tends to appear uniformly in the body rather than to seek out particular organs.

The reasons that strontium 90 is a hazard to man are as follows:

1. Strontium 90 results from about 3½ percent of all the fissions that occur in nuclear explosions;

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[10] That is, if strontium and calcium appear in soil in the ratio of 1 part to 4, and if a man eats food all grown on that soil, then a discrimination factor of 4 means that strontium and calcium will appear in his bone in the ratio of 1 part to 16, allowing some time for this to occur.

[11] The term "half life" is used to denote the period of time it takes a given quantity of an element to lose half its radioactivity. Thus, strontium 90, with a half life of 28 years, will lose 50 percent of its radioactivity by the end of that period. Then, the remaining radioactivity will again be cut in half by the end of the next 28 years, and so on.

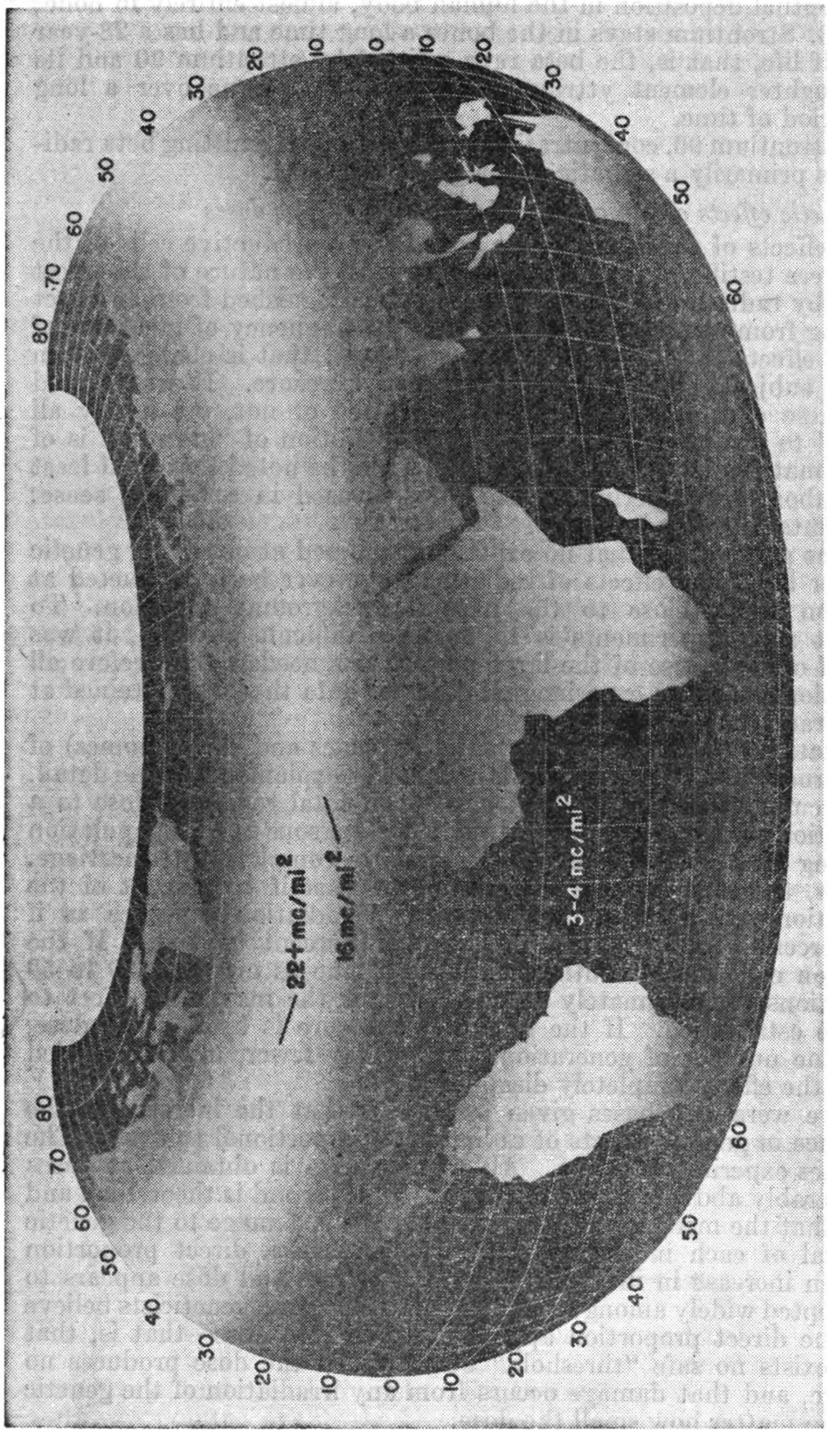

FIGURE 2.—General levels of present world-wide fallout deposition. The units of measurement are millicuries per square mile (mc/mi^2). A millicurie is 1/1000 of a curie. A curie corresponds to 3.7×10^{10} disintegrations per second. [Figure reprinted from testimony of Drs. Langham and Anderson, Los Alamos Scientific Laboratory]

2. Strontium participates in biological processes resulting in eventual deposition in the human body, almost entirely in bone;
3. Strontium stays in the bones a long time and has a 28-year half life, that is, the beta rays emitted by strontium 90 and its daughter element yttrium 90 irradiate the bone over a long period of time.

But strontium 90, concentrating in the bones and emitting beta radiation, is primarily a somatic, not a genetic, hazard.

The genetic effects of radiation with emphasis on low doses

The effects of radiation on the genetic or reproductive cells of the body were testified to be nonspecific, that is, the nature of the effect caused by radiation cannot in general be distinguished from an effect resulting from some other cause. It is the frequency of incidence of genetic effects (i. e., cell mutation or change) that is changed when man is subjected to additional radiation exposure. It was agreed that these effects, whether radiation caused or not, are nearly all harmful to the human organism. The definition of "harmful" is of itself a matter of value judgment. It should be noted that in at least some laboratory experiments the word is used in a limited sense: detrimental to reproduction.

It was pointed out that no experiments aimed at observing genetic or other biological effects of radiation have ever been conducted at radiation levels close to the natural background radiation. To conduct such experiments is to tackle a difficult problem, it was pointed out, because of the large populations needed. Therefore all conclusions based on experimental data use data that was obtained at higher radiation levels.

Radiation affects the genetic material (genes and chromosomes) of the reproductive cells. How this occurs was explained in some detail. The accumulated genetic effect of a given total radiation dose to a population is independent of the number of persons in that population receiving part of the total dose, assuming complete intermarriage. That is, the same genetic situation is forecast if 10 percent of the population gets a 10 percent increase in radiation exposure as if 100 percent of the population gets a 1 percent increase. If the radiation exposure is continuous, it may take as many as 30 to 50 generations (approximately 1,000 years) for the maximum effect to become established. If the radiation exposure is by a single dose, the same number of generations, or possibly fewer, may be needed before the effect completely disappears.

There were two bases given for saying that the increase of the incidence in genetic effects of radiation is proportional to dose. The first uses experimental data. All of these data is obtained at doses considerably above background levels. The second is theoretical and holds that the mechanism of genetic damage is damage to the genetic material of each individual cell. The idea of a direct proportion between increase in incidence of genetic effects and dose appears to be accepted widely among scientists. Furthermore, geneticists believe that the direct proportion applies down to zero dose—that is, that there exists no safe "threshold" below which the dose produces no damage, and that damage occurs from any irradiation of the genetic cells, no matter how small the dose.

These points are illustrated in figure 3. Note the straight line: It represents graphically what is meant by a direct proportion. But note also that it is marked "non-threshold"; the reason for this is that the line goes to the lower left corner at zero. The curved line marked "threshold" goes to zero effect at a dose *greater* than zero, and thus a "threshold" for damage is implied.

The basis for the 10 roentgens permissible level to the reproductive organs recommended in the National Academy report was shown to rest on certain assumptions concerning the genetic "doubling dose" of radiation to man. The value of the "doubling dose" used by the academy genetics committee was strongly questioned.

The nongenetic effects of radiation in a population, with emphasis on low doses

Effects of radiation on the somatic or nongenetic cells in the body apply (by definition) only to the individual receiving the radiation, not to his descendants. But whereas the *effect itself* appears only in the individual or individuals exposed, the *incidence* of the effect is spoken of in terms of a population—just as one speaks ordinarily of life expectancy when he thinks of insurance. Life expectancy itself only has meaning in the context of a population. The principal kinds of effects considered here are leukemia, cancer, lowered resistance to stresses, and premature aging and death attributable to no single cause. Nongenetic effects, like genetic effects, were testified to be in general similar in nature to those produced by causes other than radiation. Again, it is the frequency of incidence that is changed and, again, it was pointed out that no experiments aimed at observing these biological effects have ever been conducted at radiation levels very close to the natural background. As before, all conclusions based on experimental or clinical data use data obtained at higher radiation levels.

As in the case of genetic effects, two bases were given for saying that the increase in incidence of nongenetic effects of low-level radiation is proportional to dose. The first, as before, is based on experimental data all taken at higher doses. The second is again theoretical, and holds that mutation (change) of the genetic material of the nonreproductive cells (or possibly some other simple mechanism) occurs, and that the chronic nongenetic effects result from these cell mutations.

However, unlike the genetic situation, here there was substantial testimony presented against a proportional relationship between incidence of radiation effects and dose. One contention is that biological repair is an established fact for a variety of biological systems under a variety of stresses. Another contention is that these effects, that is, leukemia, cancer, etc., can be induced through a variety of biological mechanisms, and that nongenetic cell mutation or change caused by radiation may be one of these mechanisms, but only one. This contention goes on to say that even if the genetic mutation or change actually takes place, and even if the incidence of effects occurring through cell mutation is proportional to dose, the existence of other mechanisms precludes a conclusion that an overall proportional relationship exists. See figure 3 again.

It was pointed out in the testimony that a direct proportion, if it exists for somatic effects, still admits of a threshold. That is, the

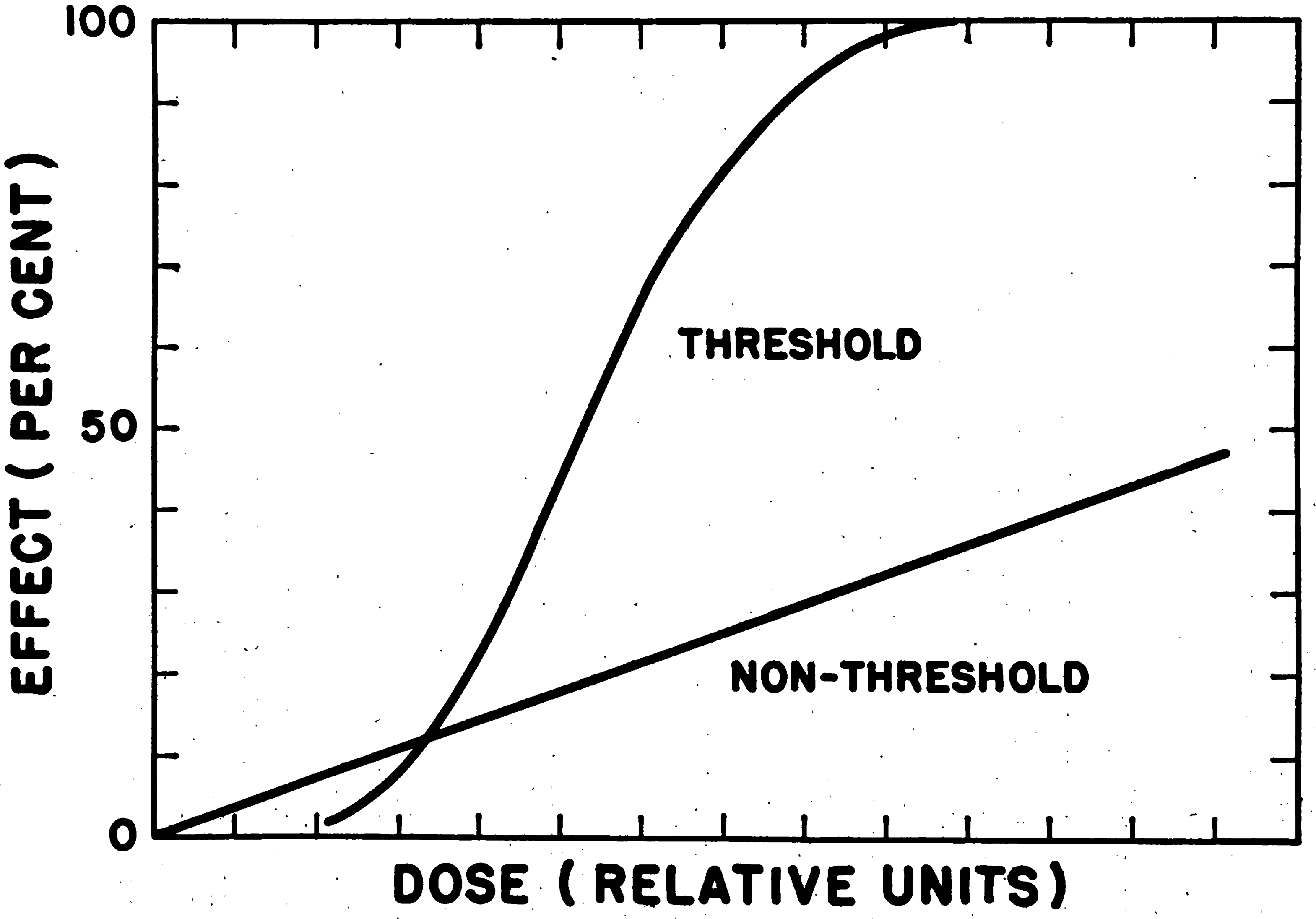

FIGURE 3.—A pictorial representation of the difference between a threshold and a nonthreshold situation. Dose increases to the right. Note that the non-threshold line is a straight line; it needn't be. (See p. 15.) [Figure reprinted from testimony of Drs. Langham and Anderson, Los Alamos Scientific Laboratory.]

straight line in figure 3 might not go to the lower left corner, but may instead cross the baseline to the right of the corner.

On the other hand, the possibility was brought out that the curved line in figure 3 might, instead of missing the lower left corner, come down to it. That is, it is possible that a "no threshold" situation might exist in which the effect-dose relationship is not a direct proportion.

Maximum permissible dose (of external or internal radiation) and maximum permissible concentration (of internal radioactive emitters)

The semantics of these words, as well as their meanings in fact implies the existence of a "permissible," dose. In wording the definitions of "maximum permissible dose," scientists generally use words to the effect that such a dose is not necessarily absolutely "safe."[12] The evolvement of policy in this field therefore involves not only scientific but moral considerations as well. Nevertheless, as the testimony pointed out, in actual derivation the concept of maximum permissible dose is based on the notion of the dose it takes to produce a "detectable" nongenetic effect, that is, the notion of a threshold; once the threshold is established, a factor of safety then leads to the values presently established for "maximum permissible dose" and "maximum permissible concentration."

If in fact any quantity of radiation, however small, produces a biological effect, that is, if there is no threshold, then the concept implied by "maximum permissible dose," developed primarily for industrial workers, as presently used is erroneous. The alternative in a world where worldwide manmade radiation is a fact, is to define and establish a "population average acceptable dose." Such a notion implies a willingness to accept a predetermined specified quantity of radiation in a population.

The "maximum permissible concentration" of strontium 90, a bone seeker, is based on a "maximum permissible body burden" in adults, established by direct experimental comparison of the biological effects of radiostrontium and radium in animals. The permissible body burden of radium actually used in the comparison for human beings is based on extensive human experience with "radium poisoning." The value now used for the maximum permissible concentration of strontium 90 in man is 1 microcurie per kilogram of body calcium (1,000 strontium units) for an "occupational dose" or 0.1 microcurie per kilogram of body calcium (100 strontium units) for a "population dose."

To reiterate, the great unknown in the field of nongenetic biological effects of radiation is whether there is a threshold or whether there isn't. Two recent reports, that of the British Medical Council and that of the National Academy of Sciences, deal with this question. The wealth of information presented at the hearings, together with the degree of uncertainty clearly pointed out, and the undoubted importance of an understanding of the points involved, suggest that an early reevaluation of the older data and evaluation of more recent data is essential. Such a reevaluation might lead to a change of the findings or they might be confirmed.

[12] See, for example, National Bureau of Standards Handbook 59, p. 26.

Forecasting the consequences of future weapons testing

The hearings, as has been emphasized earlier, were meant to cover all of the scientific aspects of fallout, including local fallout, delayed tropospheric and stratospheric fallout, acute radiation effects, chronic radiation effects, weapons testing effects, and the effects of nuclear war. It is clear that the keenest interest by the witnesses themselves was in the question of how to apply existing information to the forecasting of the effects of future weapons testing. This question was covered extensively in the four round-table discussions. Two of the discussion sessions (June 3 and 4) discussed primarily the question of the biological effect of low doses of radiation. On this question, little agreement was reached. The other two discussion sessions (May 29 and June 6) discussed primarily the question of how to forecast what the fallout radiation levels themselves, particularly those of strontium 90, might be corresponding to some assumed testing pattern. A number of individual witnesses prepared estimates of what the future human-bone levels of strontium 90 might be under various presupposed circumstances.[13] These estimates all ignore local fallout on the presumption that testing will occur in a controlled area.

It should be noted that indefinitely continued testing at some constant rate does not necessarily mean an indefinitely continued rise in radiation levels, for at some level the rate of radioactive decay will equal the rate of production of radioactivity. This is what scientists have called the "equilibrium level" for a constant test rate.

Individual estimates of a reasonable future permissible annual release of fission products from indefinitely continued testing ranged from about 2 megatons of fission yield equivalent per year to about 10. A value to narrow the range was not arrived at in the discussion sessions of the hearings.[14]

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[13] A paper prepared after the hearings by Dr. Wright Langham and Dr. Ernest Anderson appears in the print of the hearings. It discusses primarily the strontium 90 problem and discusses many of the forecasts also discussed in the hearings by Dr. Langham and others.

[14] At the invitation of AEC's Division of Biology and Medicine, a meeting was held on July 29, 1957. Principal participants were Mr. Eisenbud, Dr. Kulp, Dr. Langham, Dr. Libby, Dr. Machta, Dr. Neuman, and Dr. Selove. Also present were Dr. Dunham, Dr. Alexander, Mr. Hollister, Dr. Calvin J. Potts, Dr. Reitemeier, and Dr. Western. A written summary of the meeting appears in the print of the hearings. Three forecasts were made at the meeting; all predicting what the future human skeleton levels of strontium 90 in young persons might be in the Northeastern United States under various conditions.

The basis of these forecasts is an assumption that an average value of 0.8 strontium unit, based on Dr. Kulp's measurements of strontium 90 levels in the skeletons of children in the Northeastern United States, as of the fall of 1956, represents a reasonable point from which to extrapolate. Then the following 3 forecasts were developed:

1. *Forecast.*—The future skeletal concentrations in young persons in the Northeastern United States *resulting from the strontium 90 already on the ground before 1957* are predicted to fall within a range of 1.5 to 2 strontium units.

2. *Forecast.*—The future skeletal concentrations in young persons in the Northeastern United States *resulting from all strontium 90 produced before 1957* are predicted to fall within a range as follows:
   (*a*) 1.5–3.5 strontium units if stratospheric fallout is uniform;
   (*b*) 2–5 strontium units if existing fallout pattern is maintained;
   (*c*) 4–10 strontium units if predicted increase in "banding" of stratospheric fallout in latitudes of Northeastern United States occurs.

3. *Forecast.*—The future skeletal concentrations in young persons in the Northeastern United States *resulting from all strontium 90 produced before 1957 plus an equal amount produced in the next several years from a repetition of past tests* (or equivalent) are predicted to fall within a range as follows:
   (*a*) 3.5–9 strontium units if stratospheric fallout is uniform;
   (*b*) 5–12 strontium units if existing fallout pattern is maintained;
   (*c*) 10–25 strontium units if predicted increase in "banding" of stratospheric fallout in latitudes of Northeastern United States occurs.

4. *Forecast.*—The future skeletal concentrations resulting from indefinitely continued testing (often approximated by taking 100 years) at the average annual rate of the past 5 years (10 megatons equivalent fission yield per year) were *not* forecasted, nor were the effects of an increasing rate of testing considered.

The forecasts that were made (for the Northern United States) show that if the amount of fission products put into the atmosphere doubles in the next 10 years or so the bone levels should somewhat more than double. Local fallout, of course, is not included.

Note that the units used are "strontium units," defined on p. 9. The maximum permissible concentration of strontium 90, it will be recalled, is 100 strontium units for a population—subject, as stated above, to serious questions and limitations. Before any of the forecasts above, or those contained in the hearings, are compared with 100 strontium units, or some other standard, it should be kept in mind that some of the forecasts assume uniformity of stratospheric fallout distribution. If, as the hearings strongly indicate, this assumption is incorrect, then the forecasts need adjustment before a comparison is made.

It is to be noted that this group did not go as far into the future, in making forecasts, as some of the individuals did.

The main points of uncertainty that make the longer range forecasts so hard to do are—

1. What the future testing pattern will be. The assumption has often been made of a constant average annual rate of testing. But the testing up to now has been sporadic. The concept of "present rate of testing" is in any exact sense meaningless. Not only the *rate*, but the kind and location of testing are important and difficult to predict.
2. What the degree of nonuniformity of fallout in the atmosphere really is.
3. What the storage times in different parts of the atmosphere and in different geographical regions of the globe are.
4. How the fallout will behave under the different geological and biological conditions that exist around the world.
5. How fallout will distribute itself in a human population.
6. Whether a threshold for radiation damage exists or not.
7. How to arrive at an acceptable maximum permissible concentration of radioactive isotopes in man.

In the absence of better, or better substantiated, forecasts of the consequences of continued weapons testing, whether for 10 years or indefinitely, the question of how much and what kind of testing is "acceptable" is very difficult to answer. Even if the information were available now, the question still requires the exercise of judgment. As this report has repeatedly stated, not only scientific but moral issues, and issues of broad national policy, are involved.

It appears difficult, based on the hearings, to justify extreme statements concerning the consequences of further testing, at or less than at the level of the past 5 years, unless one is willing to make judgments in the absence of information. It is no doubt true that judgments of this sort will always have to be made without full information. But the rapidity with which information is now being gathered, and the vigor with which future information-gathering activities perhaps will occur, suggest that each year's passing will help significantly in the making of judgments. When all of the factors concerning weapons testing are evaluated to arrive at a policy, it might be remembered that information is rapidly becoming available.

Pending a resolution of the differences and uncertainties discussed in this report, among others, it would appear that the consequences of further testing over the next several generations at the level of the past 5 years could constitute a hazard to the world's population.[15] If the level of future testing rises, then the hazard could be greater and could arrive sooner. Individuals, of course, may as in the past receive exposures from local fallout that exceed presently established permissible levels.

The research program

Originally it was planned that a specific part of the hearings would be devoted to discussing the research program. However, several witnesses not scheduled for that part of the hearings nevertheless submitted testimony on the subject, and some of the discussion time was devoted to it also. The result is a record rich in ideas as to what is good and bad about the present program and what should be done

[15] As noted elsewhere in the report, the committee has not yet considered the possible hazards from other sources of radiation such as fluoroscopes, X-ray machines, etc. Therefore the committee has not considered the question of how the fallout hazard might compare with these other hazards.

in the future. It is to be hoped that such agencies as the Atomic Energy Commission, and the National Academy of Sciences will dig through the record and evaluate the ideas.

Manpower and education of manpower are emphasized often. To talk of programs without thinking of the manpower to carry them out was deplored. In fact, a recommendation was made that the AEC emphasize manpower education and development in the biological and associated sciences.

A well-balanced program exists now in the AEC's Division of Biology and Medicine (Dr. Charles L. Dunham, Director), according to testimony given. A well-balanced program as the primary need for the future was also spoken for. In particular, there was testimony advocating that long-term basic research not be lost sight of in a multitude of short-lived programmatic research projects. Many specific proposals for research projects appear in the record.

Although the testimony expressed satisfaction with existing research programs, the general tone seemed also to advocate a stepped-up program for the future. Part of the reason for the stepping up, it was pointed out, is that past programs have borne fruit; many specific unknowns have been discovered, which new effort can be put on.

Some of these areas for further research are—

1. The behavior of particulate matter in the atmosphere, particularly the stratosphere;
2. The absorptive capacity of the biosphere for fallout products such as strontium 90;
3. The selectivity of biological systems for particular isotopes;
4. The response of biological systems to low doses of radiation;
5. The application of biological knowledge obtained from an experiment on an individual to large populations and vice versa.

Information availability and exchange

One point the committee was interested in was whether or not scientists, many of whom are employed by Government agencies, felt free to work and to exchange information in the sciences related to fallout. The weight of the testimony was that such freedom exists.

Another point the committee was interested in, and one on which the testimony is not so satisfying, is whether or not information on fallout and its effects is reaching the public. Information on the biological effects of radiation, from whatever source, has been presented to the public in widely read reports by the British Medical Council and by the National Academy of Sciences. These reports contain some information directly applicable to the fallout question. But information on fallout itself has evidently not reached the public in adequate or understandable ways. That this is so is evidenced by the need for, the results of, and the interest in these hearings.

These hearings do not contain significant amounts of scientific data discovered just for the sake of the hearings. If much information that was new was made available as a result of the hearings, this occurred for principally one of two reasons:

1. The progress of research is so rapid that new information developed in late 1956 and early 1957 was ready for initial presentation at the hearings.
2. The information already existed but had not been made available generally.

And there should be no doubt that much new information was made available. Information was disclosed as follows:

(1) Concerning the work by weather people on predicting fallout patterns and, in particular, concerning the mechanisms of nonuniformity of stratospheric fallout;

(2) Presenting the results of soil sampling and assaying from around the world, confirming the nonuniformity of existing fallout;

(3) Concerning past testing activities in Nevada in far greater detail than had generally been known to be available;

(4) Concerning the "clean" weapons situation;

(5) Concerning the importance of strontium 90 in *local* fallout;

(6) Concerning the importance of countermeasures and the need for operational information (this point will be discussed below);

(7) Concerning the most recent evaluations of what the best values for ground-to-bone strontium 90 discrimination factors should be;

(8) Concerning the behavior of strontium 90 in soils;

(9) Concerning the question of threshold effects, "detectable" effects, and maximum permissible concentrations;

(10) Presenting, in spite of disagreements, quantitative estimates of future radiation levels.

The need for operational information

The result of a research effort is information. But this information is not necessarily directly applicable to solving a problem. For example, the newly issued handbook, The Effects of Nuclear Weapons, prepared by the Department of Defense and the Atomic Energy Commission, covers at length the effects of single weapon explosions of varying sizes and under varying conditions.

It is apparent, however, that the people of the world and their governments lack information on the operational problems—meaning information that can be acted upon in a given situation—associated with fallout. A generalized way of stating these operational problems is to pose the question: How can man survive in, and how can he respond to, an environment of increasing manmade radioactivity in peacetime and in wartime? Further information of this operational sort appears to be clearly needed covering—

First, industrial and weapons sources of radioactive contamination and radiation during peacetime;

Second, nonmilitary protection, survival, and recovery measures in wartime and in the postwar period.

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